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(54) Acoustic transducing arrangements and methods.

(57) Systems and methods are disclosed which provide an electrically passive optically controlled acoustic transceiver system which measures the quantity of a liquid (20), such as aircraft fuel, in a tank (12). Pulsed electromagnetic radiation, such as light or infra-red radiation, is guided through an optical fibre (34) and impinged upon a flexible member (30) adapted to flex when heated and transmit acoustic pulses. An optical fibre detector (34,42) is used to monitor the acoustic pulses reflected from the liquid level (22) in the tank (12). The system is electrically passive and does not require or use electrical power at the sensing location.

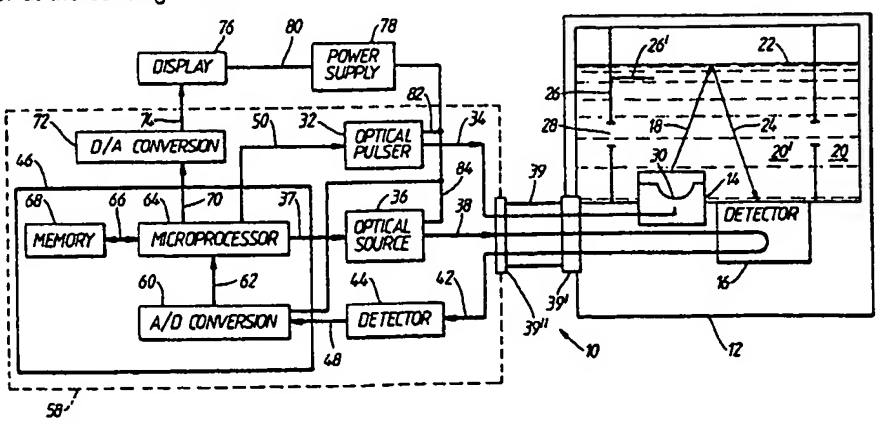

Fig.1.

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ACOUSTIC TRANSDUCING ARRANGEMENTS AND METHODS

BACKGROUND OF THE INVENTION

The invention relates to electro-acoustic transducing arrangements and methods. More particularly, the invention provides electrically passive acoustic transmission and detection for liquid quantity gauging. Embodiments of the invention are useful for fuel quantity gauging in aircraft fuel tanks.

US-PS-4 677 305 (Ellinger, assigned to Simmonds Precision Products, Inc.) discloses an opto-acoustic fuel quantity gauging system which uses an electrically activated transducer.

Brown, D.H., "Liquid Level Measurement by Ultrasonic Ranging", Central Electricity Generating Board (London, Aug. 1976), discloses the concept of an ultrasonic ranging device for measuring the liquid level in a container. An ultrasonic pulse is propagated upwardly from the bottom of the container. The propagation time between the generation of the pulse and the reception of the reflected wave is indicative of the liquid level. US-PS-4 580 448 (Skrgatic) discloses a system somewhat similar to that of Brown and which uses an ultrasonic liquid level sensor in which an ultrasonic crystal transducer mounted exteriorly of the liquid container transmits a pulse through the container wall and the liquid and detects the reflected wave to determine liquid level.

US-PS-4 334 321 (Edelman) discloses an opto-acoustic transducer by which power-modulated light is transmitted through a fibre and absorbed to generate heat which, in turn, effects expansion and contraction of the light guide to develop sound energy. The transducer is indicated as providing an audio output of between 300 and 3300 Hz.

EP-A-0 232 610 discloses a photothermal oscillator force sensor which includes a beam of silicon caused to resonate by impingement of light thereon.

SUMMARY OF THE INVENTION

According to the invention, there is provided an electro-acoustic transducing arrangement, comprising a movable member, and characterised by an input device directing electromagnetic energy into impingement on the movable member whereby to cause the member to move and emit acoustic energy, and an output device comprising a device carrying electromagnetic energy and subject to impingement thereon of the emitted acoustic energy whereby to cause modulation of the carried electromagnetic radiation.

According to the invention, there is also provided an optically controlled acoustic transmission and reception system, characterised by a tank, an electrically passive acoustic transmitter controlled by electromagnetic radiation, an acoustic receiver, a source of electromagnetic radiation, a first optical fibre, the first optical fibre being connected to transmit electromagnetic radiation from the source thereof to the transmitter which converts electromagnetic radiation into emitted acoustic energy, the transmitter being positioned to emit the acoustic energy into the tank, the acoustic receiver being positioned to receive the acoustic energy emitted by the transmitter and to produce a corresponding output.

According to the invention, there is further provided an acoustic transducing method, characterised by the steps of impinging electromagnetic radiation on an input movable member so as to cause the member to move and emit acoustic energy, and causing the emitted acoustic energy to impinge on an output movable member and thereby cause modulation of further electromagnetic energy.

According to the invention, there is still further provided a method of emitting acoustic waves into a liquid enclosed by a tank, characterised by the step of feeding electromagnetic radiation through an optical fibre into impingement on a flexible member mounted within the liquid so as to vibrate in response thereto and emit acoustic waves into the liquid.

In embodiments of the invention, an electrically passive optically controlled acoustic transceiver system measures the quantity of a liquid, such as aircraft fuel, in a tank. Pulsed electromagnetic radiation, such as light or infrared radiation, is guided through an optical fibre and impinged upon a flexible member adapted to flex when heated and transmit acoustic pulses. An optical fibre detector is used to monitor the acoustic pulses reflected from the liquid level in a fuel tank. The system is electrically passive and does not require or use electrical power at the sensing location.

DESCRIPTION OF THE DRAWINGS

Optically controlled acoustic transmission and detection systems and methods according to the invention for fuel quantity gauging will now be described, by way of example only, with reference

to the accompanying drawings, In which:-

Figure 1 is a schematic representation of one of the systems; and

Figure 2 is a schematic representation of another of the systems.

DESCRIPTION OF PREFERRED EMBODIMENTS

In an embodiment of the invention to be described in more detail, an electrically passive optically controlled acoustic transceiver system is provided which measures the quantity of a liquid, such as aircraft fuel, in a tank. Pulsed electromagnetic radiation, such as light or infrared radiation, is guided through an optical fibre and impinged upon a flexible member of an opto-acoustic transducer. The flexible member is adapted to flex when heated. The energy of each pulse of electro-magnetic radiation is rapidly absorbed as heat by the flexible member. Preferably, the flexible member is a thin semispherical shaped black-coated metal member supported to allow it to flex when heated by the pulses of electromagnetic radiation. Each flexing of the metal member initiates an acoustic pulse which is directed to travel through a liquid to an air-liquid interface from which a reflected acoustic pulse returns through the liquid to a monitoring optical fibre. The monitoring optical fibre directs light (or infrared radiation) to a detector. The travel time of each of the acoustic pulses to and from the liquid-air interface is measured by monitoring the time between initiating the acoustic pulse and detecting the return of the reflected acoustic pulse. The return of the reflected acoustic pulse is detected as a change in the properties of the transmitted light or infrared radiation.

With more particular reference to Figure 1, an electrically passive opto-acoustic liquid quantity gauging system 10 for an aircraft is shown. The electrically passive acoustic fuel quantity gauging system shown generally at 10 includes a tank 12 which supports an acoustic source 14 and an acoustic detector 16, and encloses liquid fuel 20. The source 14 transmits acoustic output pulses 18 through still fuel 20′ enclosed by stillwell 26 to the liquid-air interface 22 from which acoustic reflection pulses 24 are reflected to acoustic detector 16. The stillwell 26 is supported by the tank 12 so that the pulses 18 and 24 travel through still fuel 20′ which is less turbulent in flight than is the portion of fuel 20 which is outside of the stillwell 26. Stillwell 26 supports reference reflector 26′. Fuel flows freely into and out of the stillwell 26 through aperture 28.

The source 14 preferably includes a metal member 30 having a rounded or semispherical (concave or convex) shape supported to allow flexion of the rounded portion. Preferably, at least a portion of the surface of the metal member 30 is nonreflective and black. Optical pulser 32 pulses high intensity light through optical fibre 34 to the plate 30 which rapidly flexes thereby transmitting acoustic pulses 18. The pulser 32 is preferably a pulsed laser, pulsed laser diode, Q-switched laser or optically pumped Q-switched laser.

The optical source 36 transmits light through optical fibre 38 to acoustic detector 16. Reflected acoustic pulses 24 impinge upon detector 16. The detector 16 is preferably a loop 40 in optical fibre 38. The fibre 38 may be a single mode or multimode optical fibre. The output portion 42 of fibre 38 channels the light to optical detector 44. The optical fibre 34, 38 and 42 extend through connectors 38′ and 39″ and are protected by shielding 39. Detector 44 is connected to signal conditioning electronics 46 by electrical conductor 48. Signal conditioning electronics 46 is connected by electrical conductor 50 to the optical pulser 32.

Opto-acoustic signal conditioner 58 includes pulser source 36, detector 44 and signal conditioning electronics 46. Signal conditioning electronics 46 includes analog to digital (A/D) converter 60 which is connected by electrical conductor 48 to detector 44, and by electrical conductor 62 to microprocessor 64. Microprocessor 64 sends and receives signals from memory 68 through electrical conductor 66.

Microprocessor 64 sends digital signal through conductor 70 to D/A converter 72. D/A converter 72 sends analog signals through electrical conductor 74 to display 76. Power supply 78 supplies electrical power through electrical conductor 80 to display 76. Power supply 78 supplies electrical power through electrical conductor 82 to optical pulser 32. Electrical conductor 84 is connected to power supply 78 which supplies electrical power to optical source 36. Power supply 78 supplies electrical power through electrical conductor 86 to A/D converter 60 and to the other components of signal conditioner 58 through connections not shown.

By detecting and indicating changes in the light signal from the optical source 36, the return of the reflection pulses is detected and used to indicate the quantity of fuel in tank 12. The detector 44, which is preferably a photodetector, receives electromagnetic radiation, such as light, from the output portion 42 of optical fibre 38. It will be understood that any type of physical movement of the optical fibre 38, such as slight bending, in response to impact of the reflected acoustic pulses, will have an effect upon the light transmitted therethrough. Various parameters (or properties) of the light can be detected, such as back scattering sites, discontinuities, attenuation, and the like. The movement of the optical fibre caused by the impact

of the returning acoustic waves (reflection pulses) causes changes in the properties of the light signal travelling within the optical fibre. Such changes in the properties of the light in the output portion of optical fibre 42 form optical information which is converted to electrical digital form in A/D converter 60 and fed into the microprocessor 64. The fuel quantity in tank 12 is determined in microprocessor 64 and signals representative of fuel quantity are displayed by display 70. The microprocessor 64 may send further signals to the optical pulser 32 to control the starting time of the acoustic wave pulses 18.

In order to carry out the level measurement, it is necessary to know the speed of sound in the fuel. Therefore, the time required for an acoustic wave pulse to travel to the reflector 26′ (a known distance) and be reflected therefrom and travel to the receiver (a known distance) is measured. The time required for an acoustic wave pulse to travel to and be reflected from the upper surface of the fuel is then measured. The level of the liquid is then accurately determined using the speed of sound in the fuel and the time required for the acoustic wave pulse to travel to and from the upper surface of the fuel. The fuel quantity and density are inferred from information stored in memory 68 about the volume of the tank 12 when filled to several levels and the speed of sound in the fuel and the speed of sound in the fuel determined from the measurement of the time for sound to travel the known distance to and from the reference reflector all as disclosed in above-mentioned US-PS-4 677 305, the disclosure of which is herein incorporated by reference in its entirety.

With more particular reference to Figure 2, an electrically passive opto-acoustic liquid quantity gauging system 110 is shown. The electrically passive acoustic fuel quantity gauging system 110 includes a tank 112 which supports acoustic source 114 and an acoustic detector 116. The acoustic source 114 transmits acoustic output pulses 118 through the portion 120′ of liquid fuel 120 enclosed by stillwell 126 to the liquid-air interface 122 from which acoustic reflection pulses 124 are reflected to acoustic detector 116. The stillwell 126 is supported by the tank 112 so that the pulses 118 and 124 travel through fuel 120′ which is less turbulent in flight than is fuel 120 which is outside of the stillwell 126. Stillwell 126 supports reference reflector 126′. Fuel flows freely into and out of the stillwell 126 through aperture 128.

The source 114 preferably includes a metal member 130 having a rounded or semispherical (concave or convex) shape supported to allow flexion of the rounded portion. Preferably, at least a portion of the surface of the metal member 130 is nonreflective and black. Optical pulser 132 pulses high intensity light through optical fibre 134 to the plate 130 which rapidly flexes thereby transmitting acoustic pulses 118. The pulser 132 is preferably a pulsed laser, pulsed laser diode, Q-switched laser or optically pumped Q-switched laser.

The optical source 136 transmits light through optical fibre 138 to acoustic detector 116. Reflected acoustic pulses 124 impinge upon detector 116. The detector 116 is preferably a loop 140 in optical fibre 138. The fibre 138 may be a single mode or multimode. The output portion 142 of fibre 138 channels the light to optical detector 144. The optical fibre 134, 138 and 142 extend through connectors 139′ and 139″ and are protected by shielding 139. Detector 144 is connected to signal conditioning electronics 146 by electrical conductor 148. Signal conditioning electronics 146 is connected by electrical conductor 150 to high intensity optical pulser 132. Opto-acoustic signal conditioner 158 includes pulser source 136, detector 144 and signal conditioning electronics 146. Signal conditioning electronics 146 includes analog to digital (A/D) converter 160 which is connected by electrical conductor 148 to detector 144, and by electrical conductor 162 to microprocessor 164. Microprocessor 164 sends and receives signals from memory 168 through electrical conductor 166. Microprocessor 164 sends digital signal through conductor 170 to D/A converter 172. D/A converter 172 sends analog signals through electrical conductor 174 to display 176. Power supply 178 supplies electrical current through electrical Conductor 180 to display 176. Power supply 178 supplies electrical current through electrical conductor 182 to optical pulser 132. Power supply 178 is connected through electrical conductor 184 to optical source 136 and through electrical conductor 186 to A/D converter 169.

By detecting and indicating changes in the light signal from the optical source 136, the return of the reflection pulses is detected and used to indicate the quantity of fuel in tank 112. The optical detector 144, which is preferably a photodetector, receives electromagnetic radiation, such as light from the output portion 142 of optical fibre 138. As explained in relation to Figure 1, any type of physical movement of the optical fibre 138, such as slight bending, will have an effect upon the light transmitted therethrough. Various parameters (or properties) of the light can be detected, such as back scattering sites, discontinuities, attenuation, and the like. Such effects on the light in optical fibre 138 result from the physical movement of the reflected acoustic waves which impact on, and result in the movement of, the optical fibre in acoustic detector 116. The optical information is converted to digital form in A/D converter 160 and fed into the microprocessor 164. Fuel quantity

measurement signals from the microprocessor 164 are displayed by display 170. Movement of the acoustic detector 116 is monitored by following the corresponding changes in the parameters of the light passing through the fibre 138, which are detected by optical detector 144 and processed in the microprocessor 164. The microprocessor 164 may send further signals to the optical pulser 132 to control the starting time of the acoustic wave pulses 118.

The metal member 130 in the acoustic source 114 is an optical absorber which absorbs the energy of the light pulses transmitted through the optical fibre 134 to the absorber from the optical pulser 132. The optical energy is converted to heat in the absorber which undergoes a rapid expansion to generate an acoustic wave pulse 118. The wave pulse 118 propagates upwardly to the surface of the liquid and a reflected wave pulse 124 is reflected downward from the liquid-air interface. The acoustic detector 116 (which may be a fibre-optic hydrophone) detects the reflected wave pulse 124. The liquid level is determined as a function of the acoustic pulse propagation time in the manner explained in connection with Fig. 1.

The liquid level may be measured by detecting the change in the intensity of the light transmitted through fibre 138. Instead, the change in the polarization state of the transmitted light is monitored. Another possibility is to use interferometrics.

Tanks in which liquid quantity may be measured using the systems disclose may be made of metal sheeting, polymeric (organic or inorganic), composite or other suitable material. Preferred organic polymeric materials include thermoplastic and thermoset polymers. These materials may include a matrix of metal, for example aluminium, thermoplastic such as polyetherether ketone (PEEK), thermoset polymer or ceramic. A preferred composite structure includes high strength filaments or fibres in a polymeric matrix such as a crosslinked epoxy or maleinide.

Epoxy resins are well established for use in making high performance composite structures which include high strength fibre.

Preferred fibre materials are metal, glass, boron, carbon, graphite, continuous or chopped, or the like, such as disclosed in US-PS-4 656 208 (Chu et al). Structures made of these composites can weigh considerably less than their metal counterparts of equivalent strength and stiffness.

The tanks may be fabricated as disclosed in US-PS-4 581 086 (Gill et al, assigned to Hercules Incorporated). Helical applicators may be used to deposit a ply or plies of continuous filaments into the form of the tank as disclosed in US-PS-4 519 869 (Gill et al, assignee, Hercules Incorporated). Alternatively, multiphase epoxy thermosets having rubber within a disperse phase may be used to make tanks, as disclosed in US-PS-4 680 078 (Bard assigned to Hercules Incorporated). Optical fibres and transceivers may be embedded in or attached to these tanks during fabrication. Attachment to the tanks of the optical fibres transceivers after construction may be carried out using the same or a different matrix material than is used to fabricate the underlying tanks.

Other matrix compositions which may be used to make tanks include poly(aryl-acetylene) as disclosed in US-PS-4 070 333, US-PS-4 097 460, and US-PS-4 144 218. US-PS-4 656 208 discloses thermosetting epoxy resin compositions and thermosets therefrom.

Claims

1. An electro-acoustic transducing arrangement, comprising a movable member (30;130), and characterised by an input device (34;134) directing electromagnetic energy into impingement on the movable member (30;130) whereby to cause the member (30;130) to move and emit acoustic energy, and an output device (16,116) comprising a device (38,42) carrying electromagnetic energy and subject to impingement thereon of the emitted acoustic energy whereby to cause modulation of the carried electromagnetic radiation.

2. An arrangement according to claim 1, characterised by an interposed object (22;122) positioned to receive and affect the emitted acoustic energy whereby the said modulation is a function of the affected acoustic energy.

3. An arrangement according to claim 2, characterised in that the interposed object is the surface (22;122) of liquid (20;120) contained in a tank (12;112) and in that the input and output means devices (34;134;38;42) are fixed in relation to the tank (12;112) whereby the said modulation is a function of the level of the liquid (20;120) in the tank (12;112).

4. An arrangement according to claim 3, characterised by signal processing means (46;146) responsive to the said modulation to produce a corresponding electrical signal and operative in dependence on that electrical signal and on stored information relating to the velocity of acoustic energy within the liquid (20;120) and physical dimension of the tank (12;120) to produce an output corresponding to the quantity of liquid in the tank.

5. An arrangement according to any preceding claim, characterised in that the movable member comprises a flexible member (30;130) adapted to flex when heated, and in that the input electromagnetic radiation is radiation adapted to heat the flexible member (30;130) by impingement thereon.

6. An arrangement according to claim 5, characterised in that the electromagnetic radiation is light or infra-red radiation.

7. An arrangement according to claim 5 or 6, characterised in that the flexible member is a curved thin member (30;130) made of metal and treated to absorb heat.

8. An arrangement according to any preceding claim, characterised in that the input and output devices comprise respective optical fibres (34;134;38;42;138;142) for conducting the electromagnetic radiation.

9. An optically controlled acoustic transmission and reception system, characterised by a tank (12;112) an electrically passive acoustic transmitter (30;130) controlled by electromagnetic radiation, an acoustic receiver (16;116), a source (32;132) of electromagnetic radiation, a first optical fibre (34;134), the first optical fibre (34;134) being connected to transmit electromagnetic radiation from the source (32;132) thereof to the transmitter (30;130) which converts electromagnetic radiation into emitted acoustic energy, the transmitter (30;130) being positioned to emit the acoustic energy into the acoustic receiver (16;116) being positioned to receive the acoustic energy emitted by the transmitter (30;130) and to produce a corresponding output.

10. A system according to claim 9, characterised in that the acoustic receiver (16;116) is electrically passive.

11. A system according to claim 10, characterised in that the acoustic receiver comprises a device (38;42;138;142) for causing modulation of electromagnetic radiation in dependence on the received acoustic energy.

12. A system according to claim 11, characterised in that the electromagnetic radiation which is modulated in dependence on the received acoustic energy is fed to the receiver from an electromagnetic source (36;136) by a second optical fibre (38;138).

13. A system according to any one of claims 9 to 12, characterised in that the tank (12;112) contains liquid (20;120) and in that the acoustic energy (16;116) emitted by the transmitter (30;130) is received by the receiver (16;116) after reflection at the surface (22;122) of the liquid (20;120) and by signal processing circuitry (46;146) responsive to the output from the receiver (16;116) for producing an indication of the quantity of liquid (20;120) in the tank (12;112).

14. A system according to claim 13, characterised in that the liquid is fuel (20;120).

15. A system according to any one of claims 9 to 14, characterised in that the acoustic transmitter comprises a flexible member (30;130) adapted to vibrate and thereby emit acoustic waves in response to impingement thereon of electromagnetic radiation in the first optical fibre (34;134).

16. A system according to any one of claims 9 to 15, characterised in that the electromagnetic radiation is visible light.

17. A system according to any one of claims 9 to 16, characterised in that the electromagnetic radiation is infra-red radiation.

18. A system according to claim 12, characterised in that the electromagnetic radiation in the first optical fibre (34;134) is infra-red radiation and the electromagnetic radiation in the second optical fibre (38;138) is visible light.

19. An acoustic transducing method, characterised by the stePS of impinging electromagnetic radiation on an input movable member (30;130) so as to cause the member (30;130) to move and emit acoustic energy, and causing the emitted acoustic energy to impinge on an output movable member (38;42;138;142) and thereby cause modulation of further electromagnetic energy.

20. A method according to claim 19, characterised in that the impinging electromagnetic radiation is carried by a first optical fibre (34) into impingement with the input movable member (30;130) and the further electromagnetic radiation is carried by a second optical fibre (38;42;138;142) part of which constitutes the output movable member.

21. A method of emitting acoustic waves into a liquid (20;120) enclosed by a tank (12;112), characterised by the step of feeding electromagnetic radiation through an optical fibre (34;134) into impingement on a flexible member (30;130) mounted within the liquid (20;120) so as to vibrate in response thereto and emit acoustic waves into the liquid (20;120).

22. A method according to claim 21, characterised by the steps of detecting the acoustic waves reflected from the surface (22;122) of the liquid (20;120) to produce a resultant output signal, and determining from the output signal the quantity of liquid (20;120) in the tank (12;112) in dependence upon the time of travel of the acoustic waves to and from the liquid surface (22;122) the predetermined speed of transmission of acoustic waves within the liquid (20;112) and dimensions of the tank (12;122).

23. A method according to claim 22, characterised in that the step of detecting the reflected acoustic waves comprises the step of passing further electromagnetic radiation through a movable member (38;42;138;142) positioned to receive the reflected acoustic waves which cause corresponding modulation of the electromagnetic radiation.

24. A method according to any one of claims 19 to 23, characterised in that the impinging and/or the further electromagnetic radiation is visible light.

25. A method according to any one of claims 19 to 23, characterised in that the impinging and/or the further electromagnetic radiation is infra-red radiation.

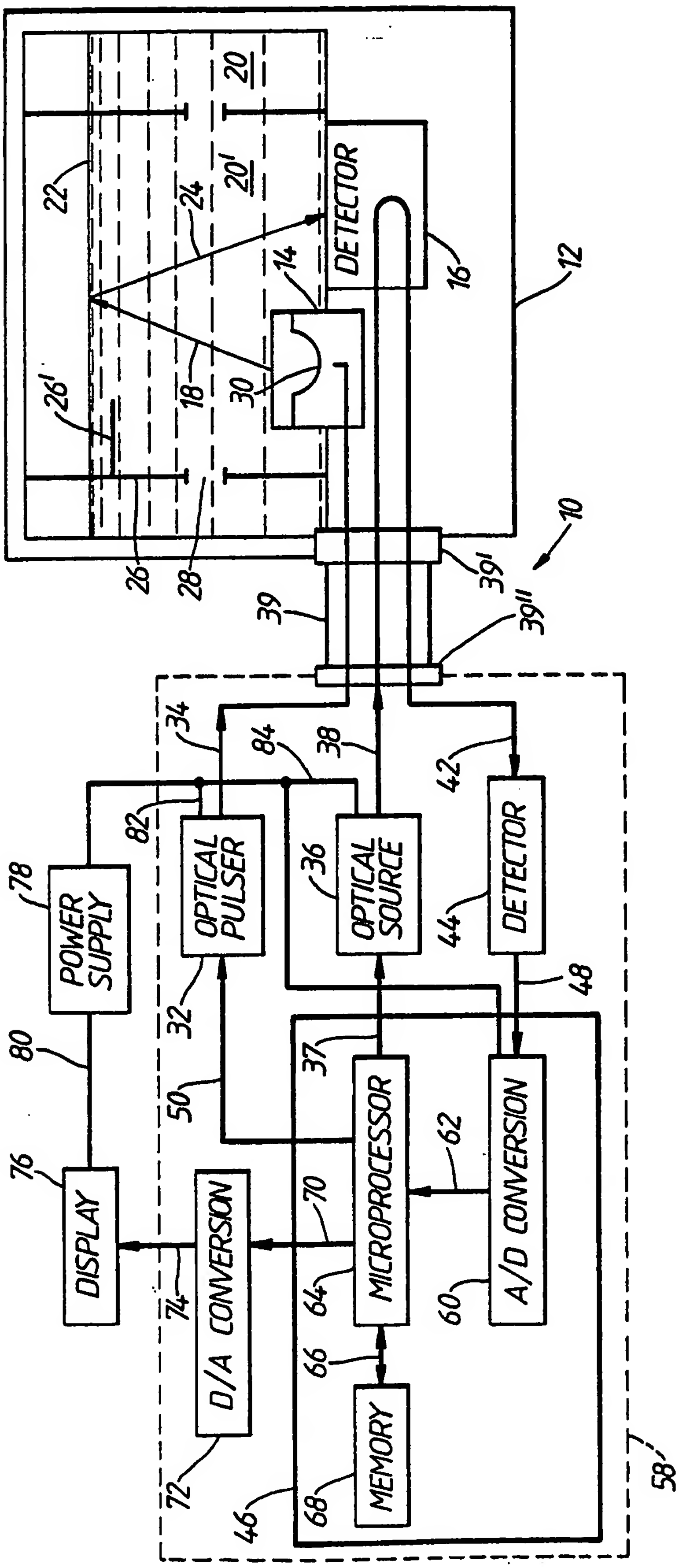
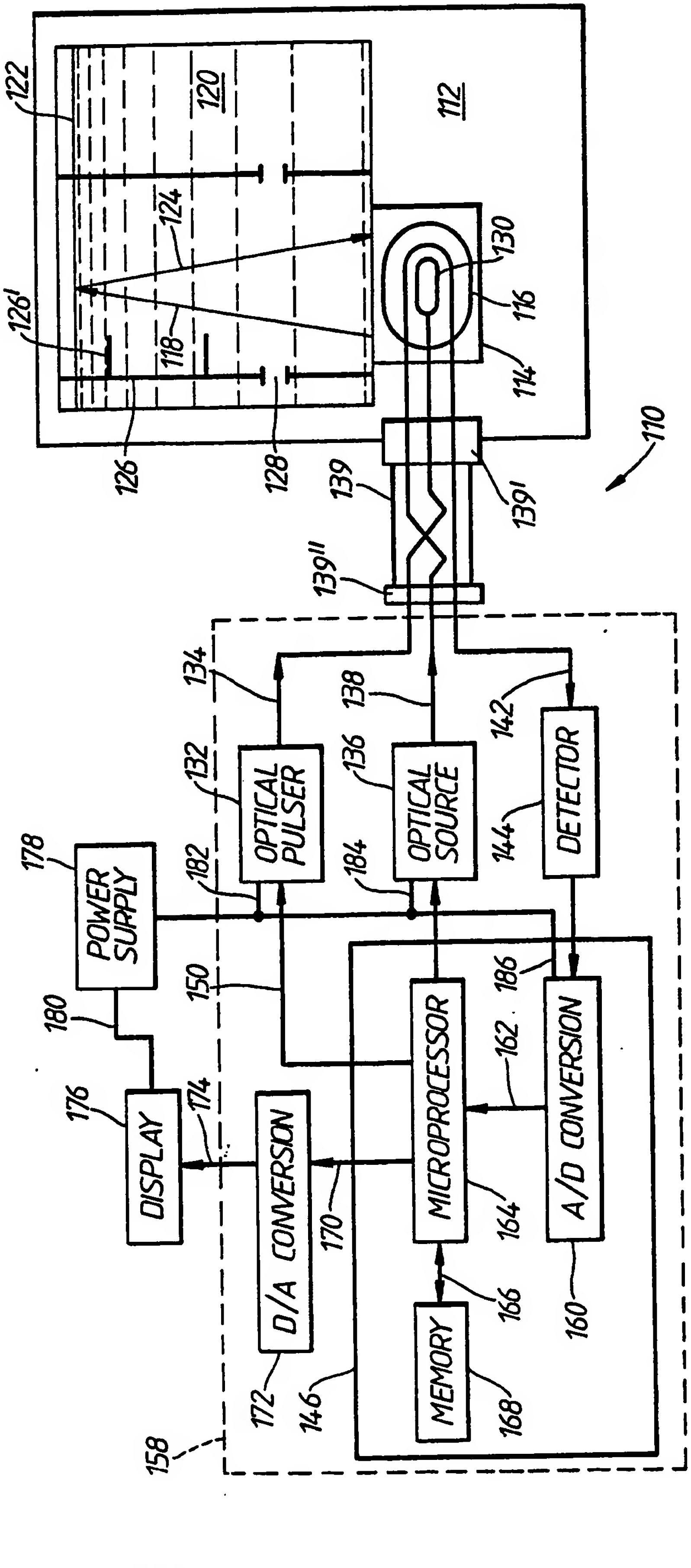

DETECTOR
OPTICAL PULSER
OPTICAL SOURCE
DETECTOR
POWER SUPPLY
MICROPROCESSOR
A/D CONVERSION
D/A CONVERSION
DISPLAY
MEMORY

Fig.1.


OPTICAL PULSER
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DETECTOR
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MICROPROCESSOR
A/D CONVERSION
D/A CONVERSION
DISPLAY
MEMORY

Fig.2